# Tunable Diode Laser for Harsh Combustion Environments

**W. Von Drasek**
**American Air Liquide, 5230 S. East Ave.**
**Countryside, Il 60525**

**Materials, Glass, and Sensors**
**Project and Portfolio Review Meeting**
**Arlington, Virginia June 21-24, 2004**

# Tunable Diode Laser for Combustion Process Monitoring

AIR LIQUIDE

**Goal:** Develop and test an industrial multiple gas near-IR diode laser sensor for **$O_2$**, **CO**, **$H_2O$** and **T**emperature monitoring targeted for harsh process monitoring.

**Challenge:** Demonstration of the technology measurement accuracy and reliability with minimum maintenance for dynamic high temperature and high particle density processes

**Benefits:** Cross-cutting technology supporting all industrial processes requiring combustion atmosphere monitoring and control.

**FY04 Activities:** Industrial testing on North Star Steel Electric arc furnace. Identify the required configuration for continuous off-gas monitoring


Diode laser Electronics and Data Acquisition System

**Participants:**

PSI PHYSICAL SCIENCES INC.

CHARTER STEEL

IMCO Recycling Inc.

Cargill Steel

**North Star Steel**

# Tunable Diode Laser for Combustion Process Monitoring

AIR LIQUIDE

- Cross-cutting technology supporting all industries requiring combustion atmosphere monitoring and control

| Barrier | Pathway | Metrics |
|---|---|---|
| •Lack of sensor technology suitable for *in-situ* process monitoring at high temperatures and high particle densities<br>•Lack of real-time sensors<br>•Lack of low maintenance sensors | •Develop multiple species *in-situ* non-intrusive laser-based measurement system<br>•Identify high temperature spectral region<br>•Multiple wavelength capability<br>•Fabricate hardened system adaptable for a variety of industrial monitoring applications<br>•Industrial evaluation for optimization | •Long-term measurement demonstration<br>•Large dynamic range<br>→Concentration (0-70%)<br>→Temperature (800 -2000 °C)<br>•Evaluate frequency and level of maintenance<br>•Measurement reliability |

***Ex. for EAF application***

| Benefits (est.) | Yearly |
|---|---|
| Energy Savings | 640 million KWh |
| Cost Savings | $19 million |

# Technology Concept

AIR LIQUIDE

Waveform Generator

Temp Control

Laser

Current Control

I(t)

TIME

- Particle Density
- Beam Steering

Collimator

Detection

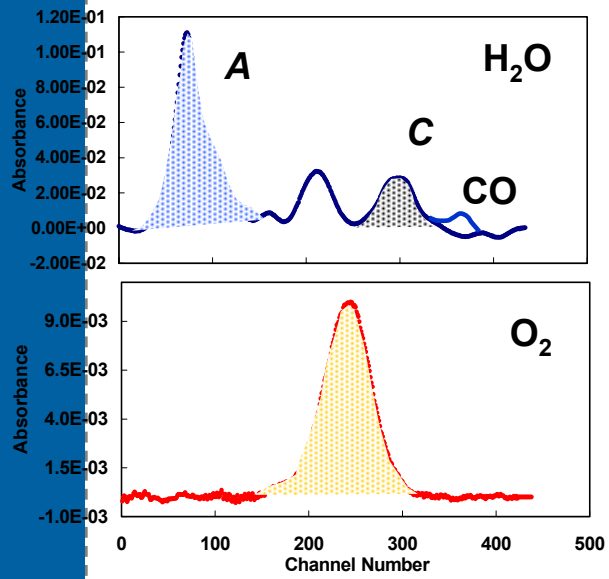
Process Interface

Background Noise Rejection

Signal Treatment

Temperature Determined from Area Ratio of Peaks A and C

Concentration Determined from Integrated Peak Areas




**Resonant absorption (Beer-Lambert):**

$$I_v = I_{v,o} \exp[-S(T)g(v-v_o)Nl]$$

Linestrength — Lineshape — Number Density X Pathlength

# Technical Progress and Outlook

AIR LIQUIDE

- Overall program progress/accomplishments to date

| Milestone | Due Date | Completion Date | Comments |
|---|---|---|---|
| ***Pilot Furnace Test Platform*** | **10/00** | **9/01** | Testing under Simulated industrial conditions |
| ***Prototype Industrial Sensor*** | **9/01** | **1/02** | Laser Supply Issue Resulted in Program Adjustments (org. 5/01) |
| ***Multi-species validation test*** | **11/01** | **2/02** | Validation and system testing CO/$H_2O$ & T only |
| ***Industrial Beam Launch & Receiver Modules*** | **11/01** | **4/02** | Broad wavelength sources |
| ***Pilot Scale Testing*** | **11/01** | **4/02** | Completed but revisited as needed |
| ***1st Industrial Field-testing*** | **1/02** | **5/02** | **Steel Reheat Furnace** |
| ***Pilot Furnace Evaluation & Refinement*** | **9/02** | **1/03** | Characterization & Calibration |
| ***2nd Industrial Test Campaign*** | **10/02** | **3/03** | **Secondary Aluminum Melter** |
| ***3rd Industrial Test Campaign*** | **2/03** | | EAF Test Completed by 12/30/04 |

# Technical Progress and Outlook

AIR LIQUIDE

- Program progress/accomplishments for last year

| Milestone/Goal | Due Date | Completion Date | Comments |
|---|---|---|---|
| **MGS System Upgrades** | **9/03** | **3/04** | Requirements for EAF. Delayed due to finalizing test agreement. |
| **MGS On-demand power control** | **12/03** | **2/04** | Add-on option |
| **Multi-section laser** | **12/03** | | Preliminary testing started but now on-hold pending available funds |
| **EAF Phase I Testing** | **10/03** | | Establish baseline performance. Installation still in-progress |
| **EAF Phase II Testing** | **12/03** | | On-demand power control & Multi-section Laser plus other enhancements |
| **EAF PHASE III Testing** | **4/03** | | Long-term testing in best system configuration Completed by 12/04 |

# MGS System Upgrades

- System modifications resulting from pilot furnace and industrial testing experience

| Modification | Driver |
|---|---|
| Historical logging of user selected parameters | Overall system evaluation |
| GUI for lineshape recording | Overall system evaluation |
| Extraneous data filtering | Use with process control |
| Soft line-locking option | Eliminate wavelength drifting |
| A/D channel crosstalk problem resolved | Remove potential noise source |

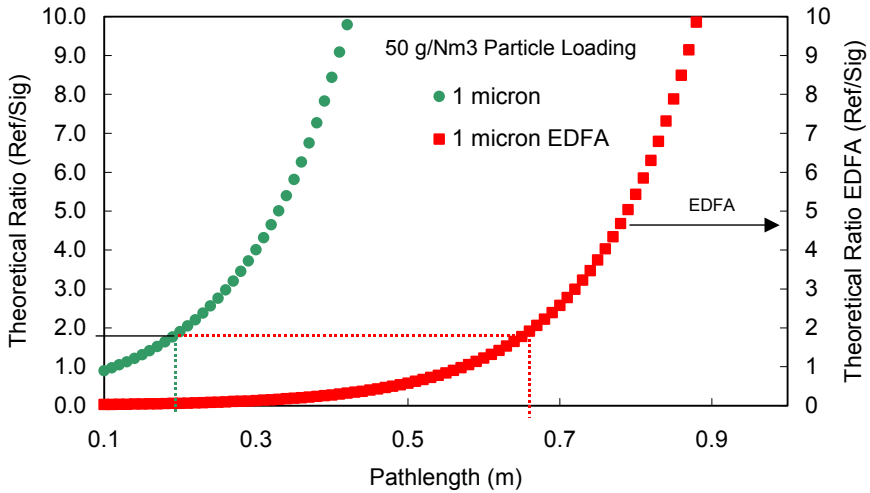
- Fiber optic communication system
  - ✓ Bi-directional
- Remote alignment
- Packaging of the electro-optic components
- Overall system hardening

} Requirements for EAF Application

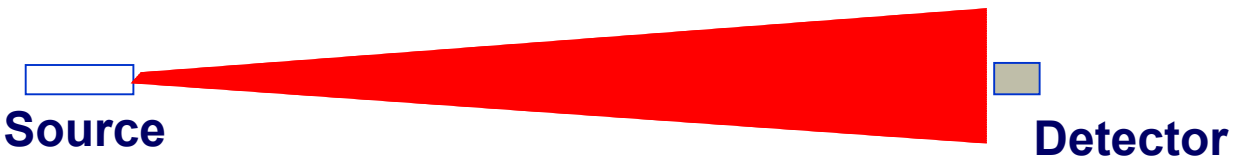
# On-Demand Power Control (ODPC)

## Technology Implementation Objective

- Improved transmission in dirty flows

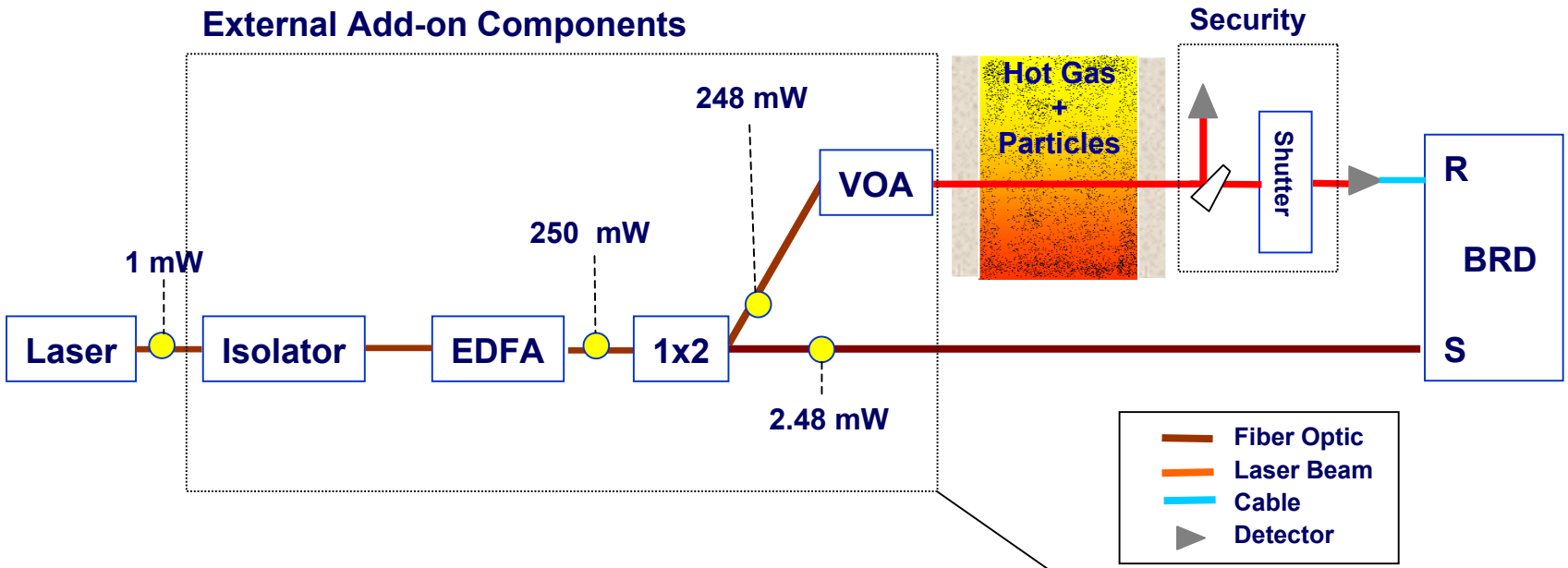



- Improved background discrimination
- Decreased sensitivity to beam steering and alignment

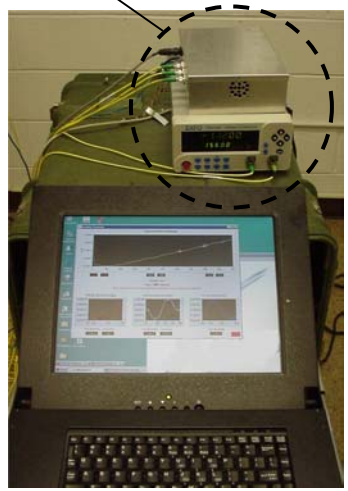


# ODPC Strategy

- System Configuration



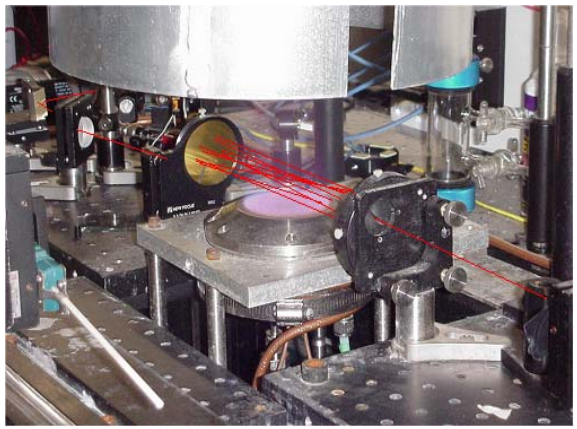

- Component Evaluation
  - EDFA Characterization
  - VOA Characterization
- Control Software Development

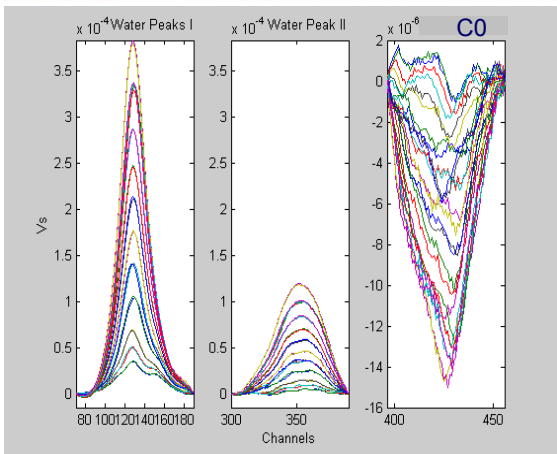


# ODPC Measurement Results

- Evaluation on lab burner

***Lab***



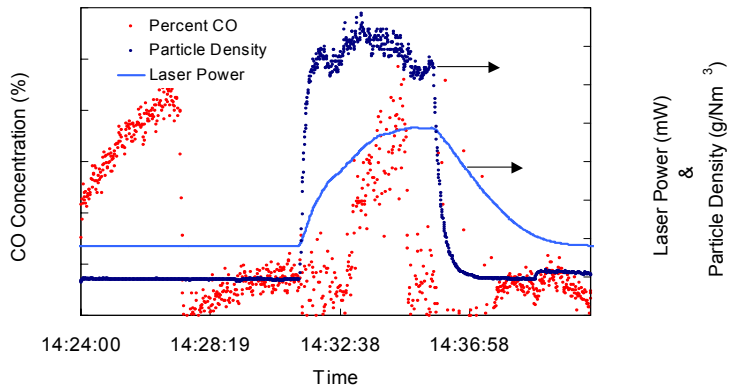


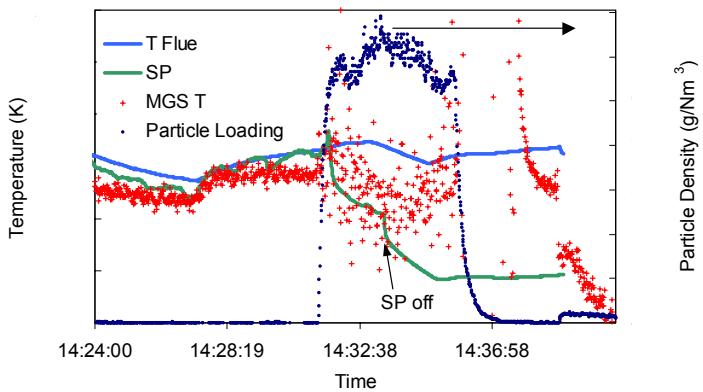

- On-Demand Power Control Software

**Pilot Furnace Exhaust**

No Seeding

With Seeding

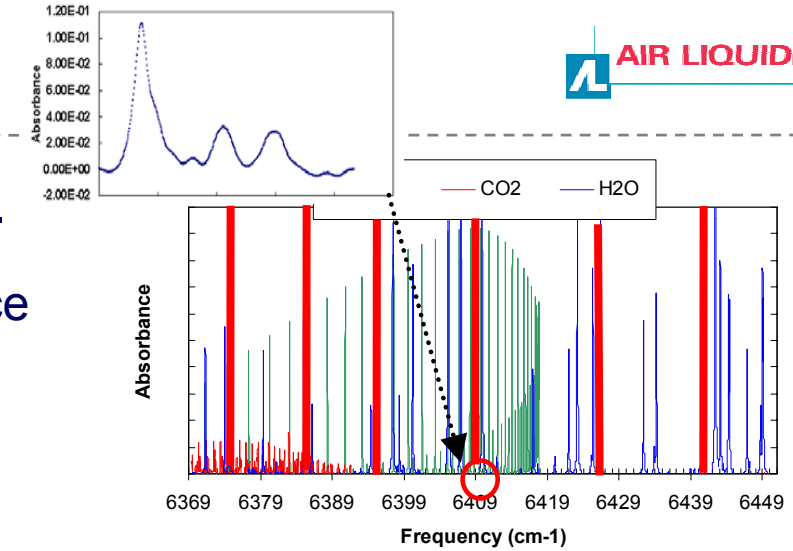


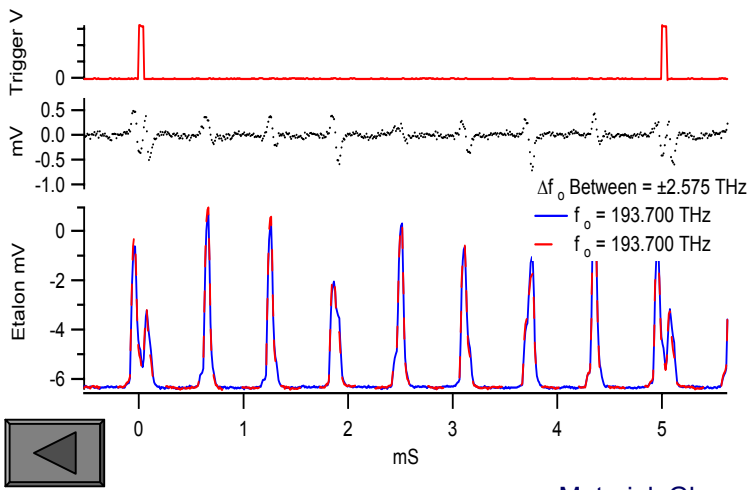
# Multi-section Laser

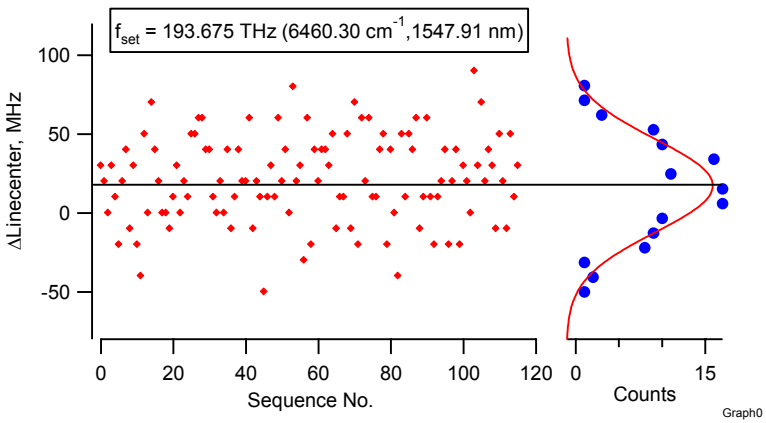
## Technology Implementation Objective

- Expanded tuning range from a single device
  - Reduced system complexity and cost
  - Improve dynamic range




- Agreement signed with manufacturer to provide prototype devices for evaluation
  - User selected scan position
- First prototype device received November 2003
- Preliminary device characterization launched



# Motivation for EAF Testing

AIR LIQUIDE

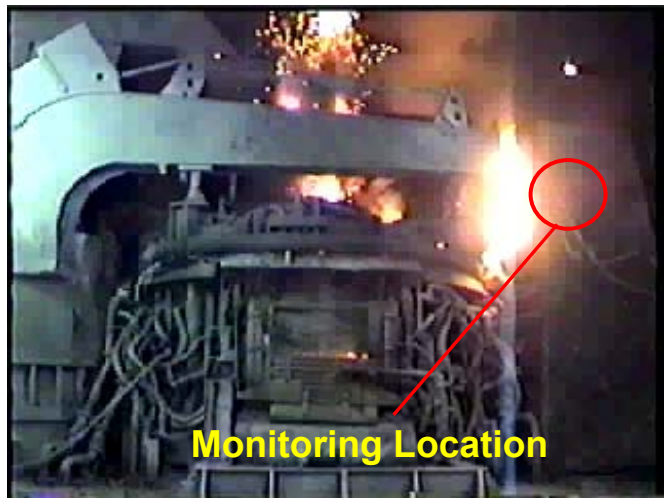
- **Considered one of the most challenging measurement applications**
- ***In-situ* Measurement Advantages**
  - **EAF off-gas Monitoring**
    - ✓ Low maintenance
    - ✓ Real-time measurement
  - ***Coupling with Post-combustion Control***

| | Theoretical real time oxygen injection | Control by set-points | Extractive Sampling | Real-time MGS |
|---|---|---|---|---|
| Savings | 9.5-12.7 kWh/t | 50-80 % | 60-70 % | 100 % |

***Potential US EAF Energy Savings → 640,000,000 KWh ($19MM)***

- **MGS System Requirements**
  - Module Hardening
  - Long-distance signal transmission
    - ✓ Immune to EMI
  - Alignment Stability

**Electric Arc Furnace (Steel)**

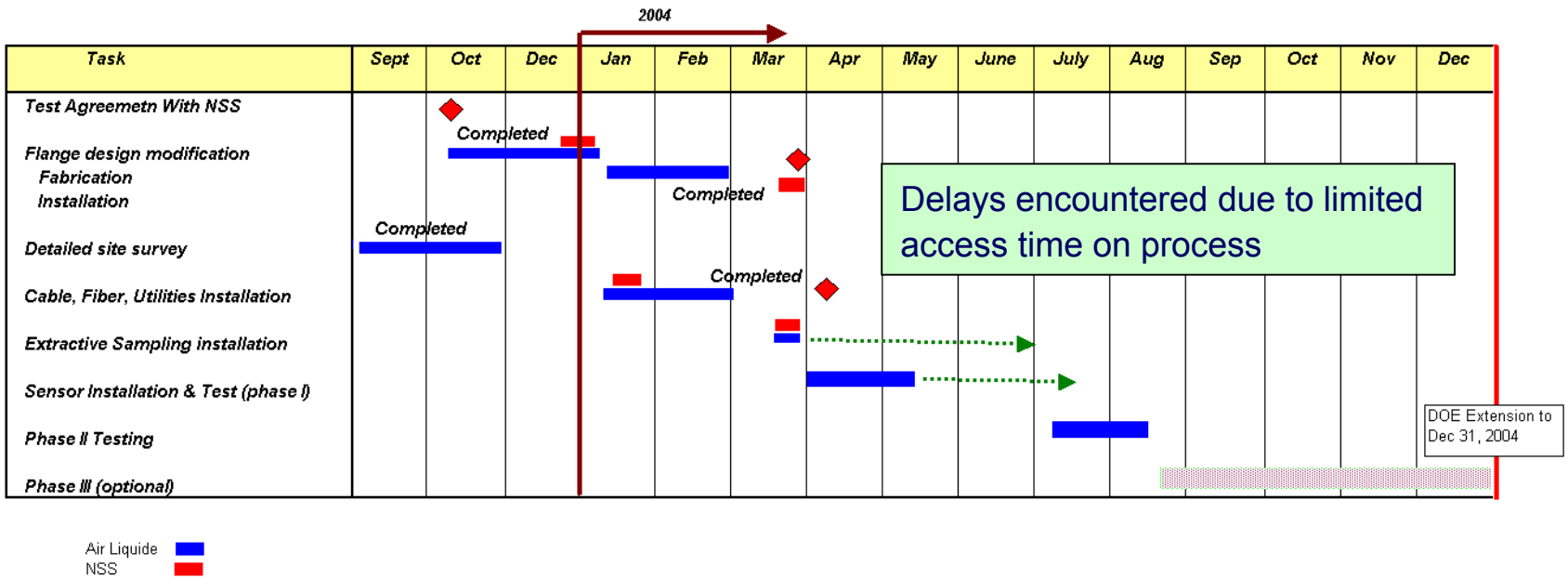



**Typical EAF Conditions**

- ✓Batch Process (60-90 minutes)
- ✓CO Profile (0-50%)
- ✓Temperature (1000-1600 $^{o}$C)
- ✓Particle Density –> 150 g/Nm$^{3}$

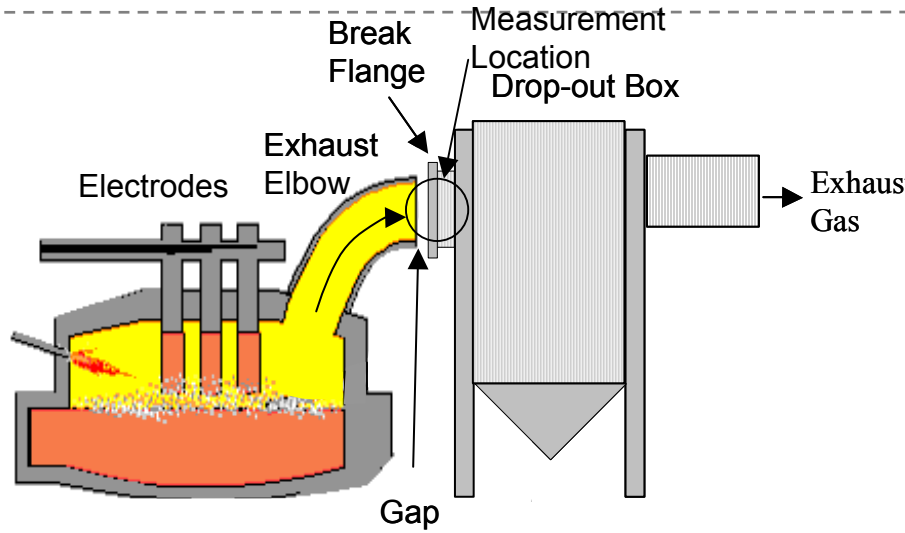
# EAF Testing Plan

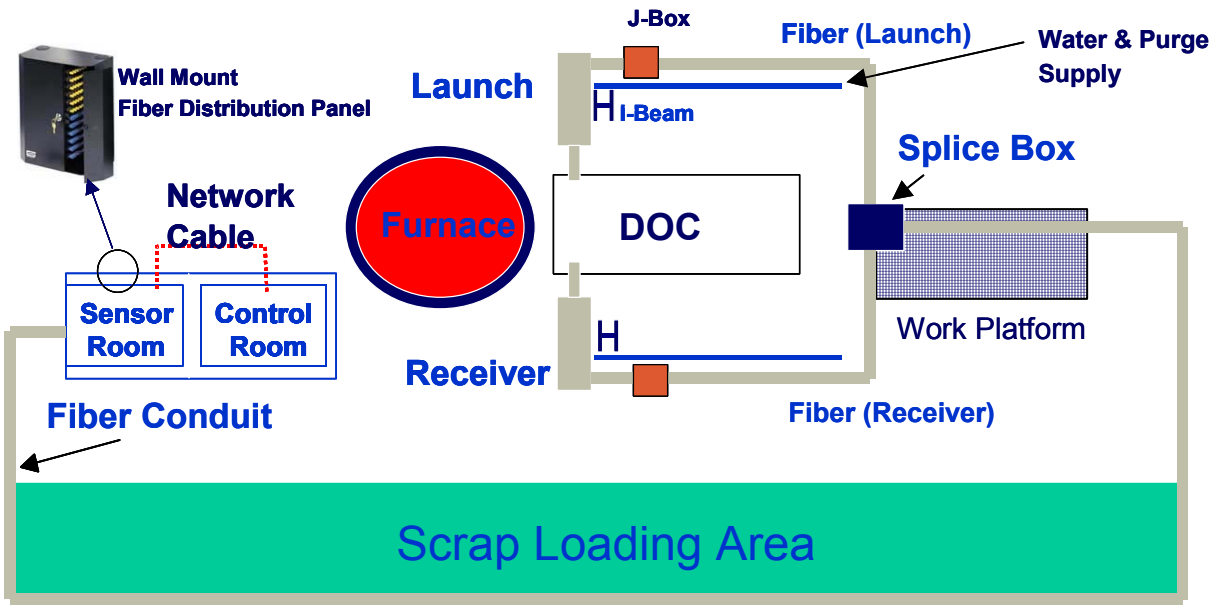
- Phase I
  - Basic configuration (Laser system)
  - Hardened modules
  - Fiber optic communication
  - Remote alignment
- Phase II
  - On-demand power control
  - Enhancements based on Phase I results
- Phase III
  - Long-term testing in best configuration
  - Measurement reliability
  - Maintenance evaluation



# NSS Process Modifications

- **Installation Requirements**
  - ✓Line-of-sight access
  - ✓Rigid module mounting
  - ✓Cooling water supply
  - ✓Purge gas supply
  - ✓Fiber Optic Cabling



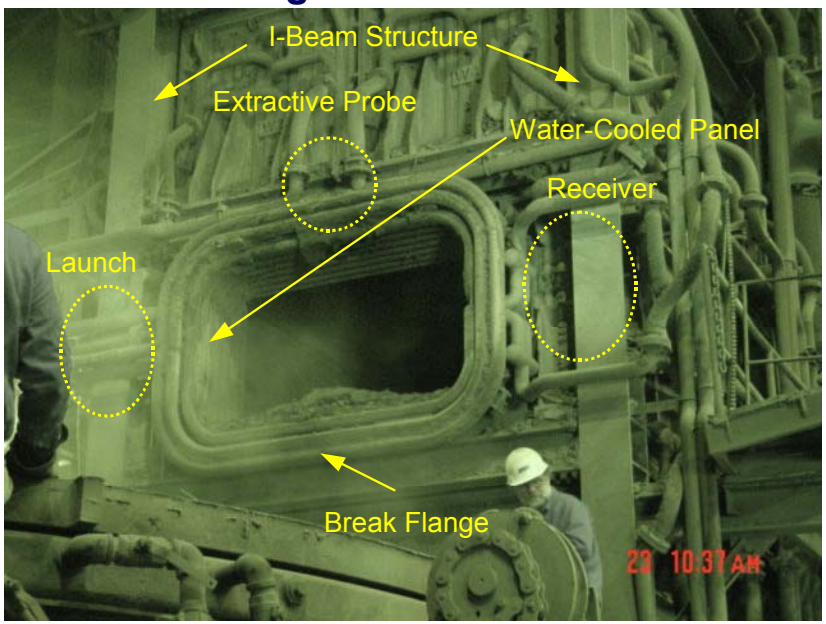

**Total Length of Fiber Run -> 350-400 ft.**

# NSS Optical Access

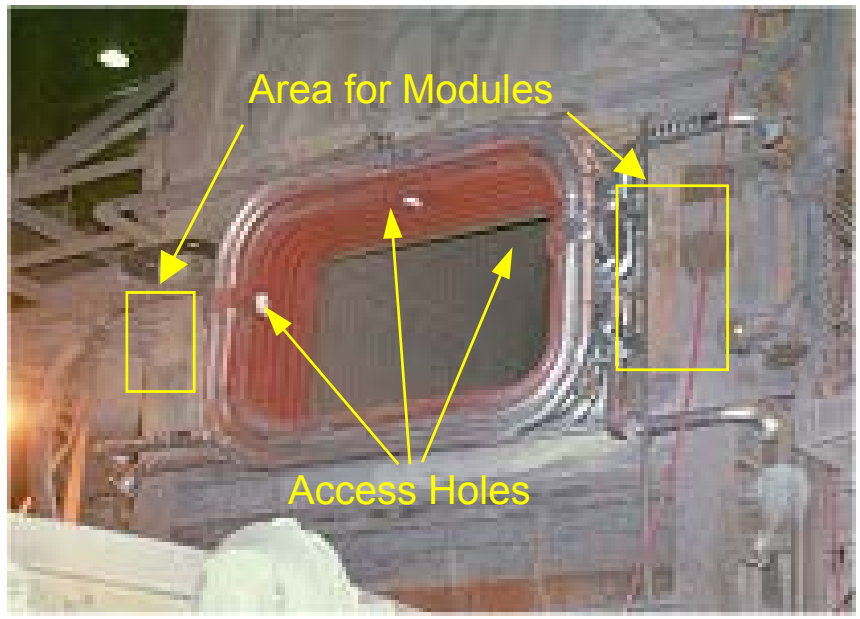
AIR LIQUIDE

- **Design and Fabrication of a new water cooled duct section**

**Existing Water Cooled Panel**

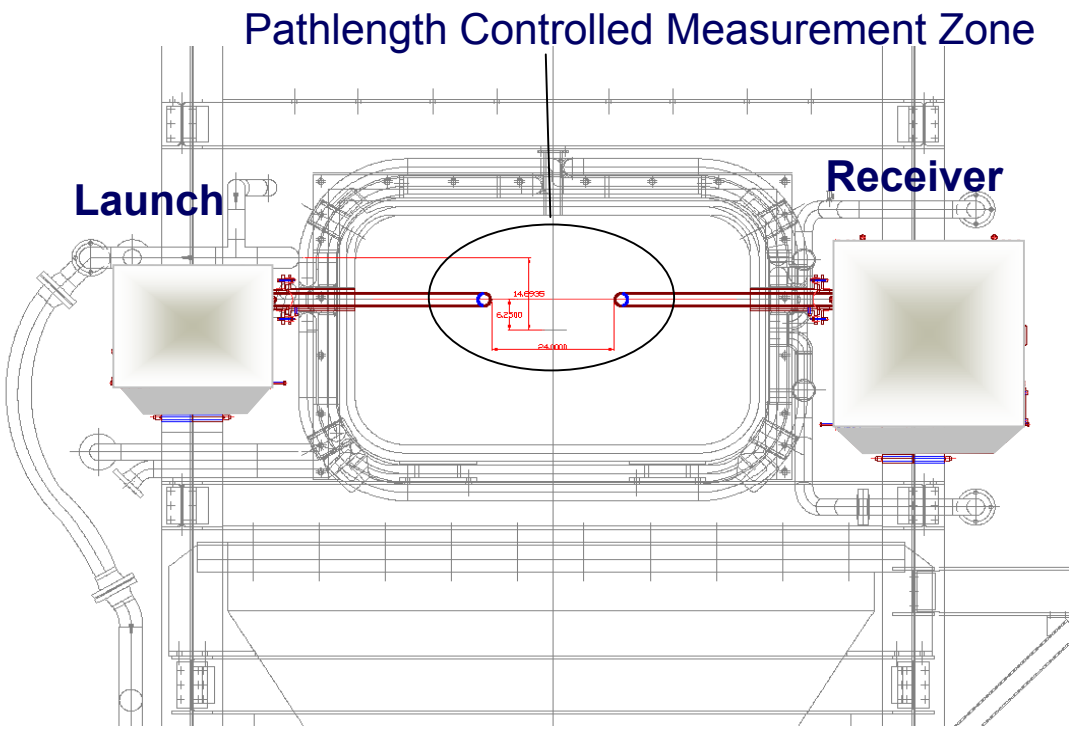



**New Panel Installed**




- Duct modification requirements
  - Reroute water feed and return lines
  - Maintain pressure drop with access ports added
- Duct design and installation completed by March 2004
- NSS cost-share of ~$35K incurred from lost production from installation

# NSS Module Design and Process Interface




- **Module support on main I-beam structure**
- **Design incorporates alignment adjustment**
- **Water-cooled Faraday cage module for electro-optic components**
  - Water-cooling shields against intense radiation load
  - Heat-sink for multiple electronic modules and power supplies
  - Dual box design will guard against EMI and EMF
  - Protection against flying debris

# Market Potential

- Commercialization plan
  - Identified Instrument manufacturing partner
    - Well established industrial instrument manufacturer
    - Experience in TDL systems
    - Technology transfer initiated
  - Develop Commercial Offer
    - 2004 time horizon
    - Sensor technology/process control
    - Selected markets
    - System tailored to process needs
- Continued Development Post-OIT
  - Synergy with manufacturing partner
  - Technology evaluation and integration
    - Multiplexed systems
    - Emerging laser technology
  - Explore new applications

# Program Summary

- Industrial Prototype Development
  - Spectral region identified
  - Single line-of-sight access for multiple wavelength launch and receive design (.76 μm & 1.5 μm)
  - Thorough testing on pilot furnace under industrial simulated conditions
  - Incorporate On-Demand Power Control system
  - Process interface designs developed for different monitoring applications
- Industrial Process Monitoring
  - Steel reheat furnace monitoring (2001-2002)
    - Detected dynamic process conditions
    - Measurements near billet surface
    - Hot installation sensor
  - Reverberatory aluminum melter (2002-2003)
    - *In-situ* monitoirng near bath
    - Performed low-level process adjustments → Fuel Savings > 5%
    - Hot installation for optical access and sensor
  - EAF site preparation underway with testing starting in July 2004
- Intellectual Property/Publications
  - 6 patent applications filed
  - 7 conference papers presented